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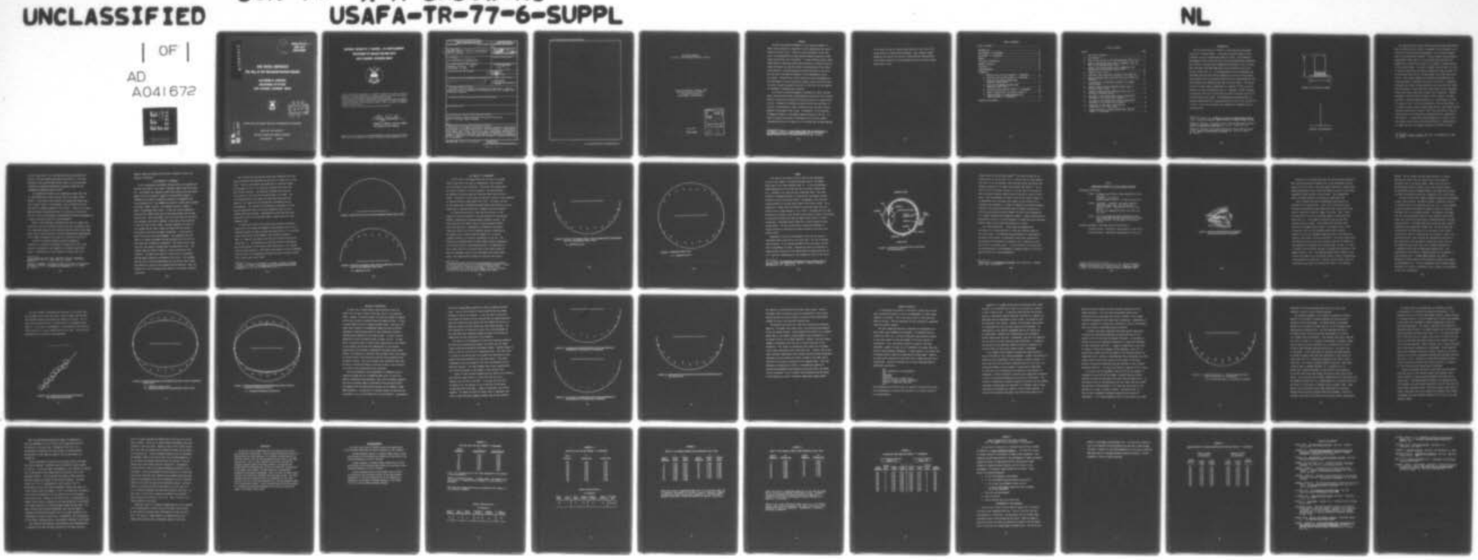

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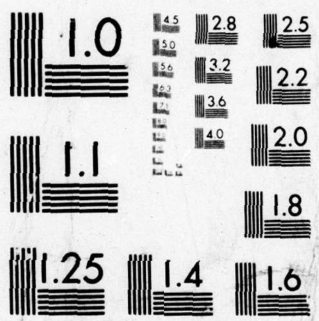

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THE FOVEA CENTRALIS
The Key to the Horizontal-Vertical Illusion

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

9

4. TITLE (and Subtitle)

6 THE FOVEA CENTRALIS, THE KEY TO THE HORIZONTAL-VERTICAL ILLUSION.

5. TYPE OF REPORT & PERIOD COVERED

FINAL REP[redacted]T.
1 Jan[redacted]975—1 Jun[redacted]76

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s) 10

Captain Alexander M. Sadowski, USAF

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Department of Physics (DFP)
USAF Academy, CO 80840

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

12 53 p.

11. CONTROLLING OFFICE NAME AND ADDRESS

12. REPORT DATE

11 Jun[redacted]977

13. NUMBER OF PAGES

50

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

14 USAFA-TR-77-6-Suppl

15. SECURITY CLASS. (of this report)

UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

This report has been cleared for open publication and/or public release by appropriate office of information in accordance with AFR 190-7 and DODD 5230.9. Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Visual Perception, Retinal Processing, Horizontal-Vertical Bias, Optical Processing, Image Processing.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is an attempt to document and explain the nature of the Horizontal-Vertical bias in the human visual system. The fovea centralis is identified as the probable cause of this bias due to its role in the dynamic scanning process of the human visual system. Also, the torsional scanning mode of the fovea centralis is postulated as performing the function of a recalibration mechanism. In addition, suggestions for future studies are presented in a general discussion of the phenomenon.

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THE FOVEA CENTRALIS
The Key to the Horizontal-Vertical Illusion

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June 1977

FINAL REPORT

PREFACE

Accurate and detailed information in the physical dynamics of human visual perception is important in fully implementing the overall mission of the Air Force. Errors in visual perception, at the very least, are bothersome but in rapid decision making situations in high speed aircraft they can be disastrous. In space vehicle systems, where normal physical reference systems and sensations are lacking, errors in visual perception can adversely affect the efficiencies of the individuals concerned. Much psychological work has been done in this area, but the work in the physical dynamics of this phenomenon has been very sparse. Detailed work in this area will be most advantageous in the development of visual systems for remotely piloted vehicles, heads up cockpit displays, prosthetic devices for the blind, and data gathering equipment in unmanned space vehicles.

In the past* we had investigated a technique for rapid, detailed object outline analysis that could possibly be the basis of the retina's ability to correctly distinguish and identify objects in a given field of view. Although the technique was quite accurate and efficient, it was just a starting point, since it addressed only the static mode of analysis of the human visual system. Consequently, it was necessary to expand our theory to the dynamic analysis process of the eye. In order to do this we decided to investigate one of the more common illusions that the eye is subject to, in the hope that an understanding

*Alexander M. Sadowski, A New Retinal Model and its Application to The Computer Analysis of Aerial Photographs OSC TR 70 (Tucson: Optical Sciences Center, The University of Arizona, Nov 1971).

of the cause of such an illusion would provide a vital clue to the actual process of human visual perception. This technical report documents our study of the top hat illusion and the identification of the fovea centralis as a most probable cause for the non-circular human field of view.

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INTRODUCTION

The Horizontal-Vertical Illusion is a most persistent and common illusion to all human beings. It has been a recurring subject of the literature for over a hundred and twenty-five years. Both Helmholtz[1] and Künnapas[2] credit Fick's 1851 work "De errore quodom optico asymmetria bulbi effecto" as having first documented the constancy of this illusion. Many individuals have been made aware of this illusion by way of the Top Hat Illusion (Fig. 1). In the demonstration of this phenomenon the individual perceives the vertical dimension of the hat as being significantly greater than the horizontal dimension and is always amazed to find upon measuring both dimensions that they are in fact equal. The Top Hat Illusion can more simply be depicted as an inverted "T" and is no less effective in such a presentation (Fig. 2). Künnapas, in 1958[3], advanced the hypothesis that this illusion was the result of the oval form of the perceived human visual field. The experiments he performed quite convincingly demonstrate that the perceived field of view is not circular but is oval in form with the vertical axis compressed as compared with the horizontal axis.

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[1]James P.C. Southal, ed., Helmholtz's Treatise on Physiological Optics, Vol III (Menasha, Wisconsin: Optical Society of America, 1925), p. 230.

[2]Theodor M. Künnapas, "An Analysis of the 'Vertical-Horizontal Illusion,'" Journal of Experimental Psychology, Vol. 49, No. 2 (1955), p. 134.

[3]Theodor M. Künnapas, "The Vertical-Horizontal Illusion and the Visual Field," Journal of Experimental Psychology, Vol. 53, No. 6 (1957), pp. 405-407.

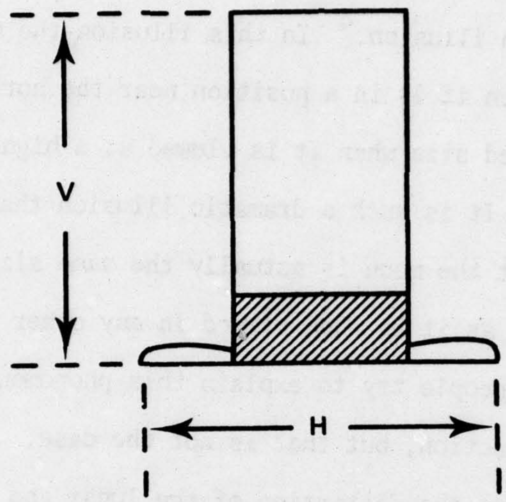

FIGURE 1. THE TOP HAT ILLUSION

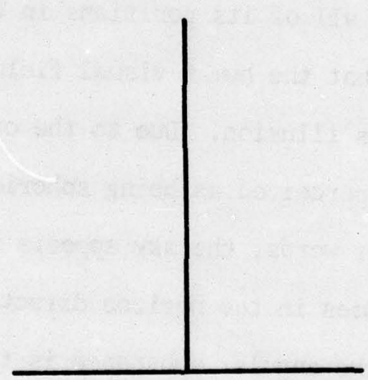

FIGURE 2. THE INVERTED 'T'

The concept that the visual field perceived by human beings suffers from a distortion in the vertical as compared to the horizontal can be arrived at from other perceived phenomena. One of the most dramatic ones is the horizon moon illusion.[4] In this illusion the moon appears significantly larger when it is in a position near the horizon as compared to its perceived size when it is viewed at a higher position in the celestial dome. It is such a dramatic illusion that it is hard to convince oneself that the moon is actually the same size when it is in the horizon position as it is when viewed in any other position in the sky. Often times, people try to explain this phenomenon by invoking atmospheric refraction, but that is not the case. Atmospheric refraction does result in the distortion of the lunar and solar disks when they appear on the horizon and it does result in their appearing earlier and setting later than if there were no atmosphere. However, atmospheric refraction does not result in this illusion. The moon maintains a constant angular substance (i.e., approximately one half of a degree of arc) in all of its positions in the celestial dome. If we accept the theory that the human visual field is oval shaped, then we can easily explain this illusion. Due to the oval field of view the celestial dome is not perceived as being spherical but compressed in the vertical. In other words, the sky appears to be closer to us in the vertical than it does in the horizon direction. Subconsciously, we reason that since the angular substance is the same, the moon

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[4]S. Tolansky, Optical Illusions (New York: The MacMillan Co. 1964) pp. 95-100.

must be larger when it is on the horizon because we perceive the horizon to be much further away than the sky above us. This compression of the celestial dome and its effect on the horizon moon illusion was originally postulated by Claudius Ptolemy and was confirmed by Kaufman and Rock in 1962.[5]

In considering the above we are compelled to admit that there is a most definite horizontal-vertical bias in the human visual system. A line drawn in the vertical will appear much longer than a line of equal length in the horizontal, and our perception of the real world is somewhat squashed in the vertical. There are, of course, many psychological implications due to the biasing of our field of view but is this biasing purely a psychologically generated phenomenon or is there some physical basis for this phenomenon?

There is some additional information that tends to support the possibility that this horizontal-vertical bias has some physical basis. It is apparently pinned to some internal reference system in the human head, since tilting the head to a position approximately perpendicular to its normal orientation will result in a reversal of the bias.[6]

In order to determine whether a physical mechanism is involved it is necessary to determine the magnitude of such a bias and also to determine if any symmetry in the human visual field exists. A modification of the inverted "T" illusion due to its

[5] Lloyd Kaufman and Irwin Rock, "The Moon Illusion," Scientific American Vol. 207, No. 1 (July 1962), pp. 120-130.

[6] Theodor M. Künnapas, "Influence of Head Inclination on the Vertical-Horizontal Illusion," The Journal of Psychology, Vol. 46 (1958), pp. 179-185.

inherent simplicity seemed to be the best technique to obtain the necessary information.

THE INVERTED "T" EXPERIMENT

In our experiments a horizontal line was used as the standard and subjects were asked to draw lines at different angles from the horizontal. Each subject was required to draw these lines so that they would appear to him to be equal in length to the horizontal standard. A standard of six inches in length was used since it appeared to be a nice workable size. The standard was drawn on a white sheet of paper utilizing a number 2 pencil. The subjects also used a number 2 pencil in generating their lines. In that way, both the generated lines and the standard lines were of the same thickness and the same shade of gray. Small tick marks, the size of the period at the end of this sentence, were used to indicate to the subject the orientation of the line that he was to draw. One mark indicated the center of the standard and the other, placed two inches from the center of the standard, indicated the proper orientation. A fresh sheet of paper was used for each line attempted. The attempted lines were drawn at 15 degree increments from the horizontal but the order in which they were attempted was randomized. The subjects used a fourteen inch clear plastic straight edge in drawing their lines. The straight edge was devoid of marks so as not to provide any size reference. The papers were taped to a white wall at a convenient working height centered on the subjects' eye levels. This arrangement was used to keep the presentation in the vertical and to keep the subjects in a more or less perfect vertical position. Also, the subjects were told to maintain their heads in as vertical a position as possible.

Due to scheduling problems and severe time limitations the first time we performed this experiment we were able to utilize only 18 subjects.[7] When we accomplished this experiment we used white sheets of bond paper (8 1/2" x 11") which were oriented with their long axis in the *horizontal*. The horizontal standard line was drawn at a distance of one inch from the bottom edge of the paper. Due to the edge effects of the paper the lines that would have been drawn at a 15° angle from the standard were eliminated from our investigation. Our interest at this time was to determine if there was any significant bias in the visual system in order to see if further study was warranted. Consequently, we felt that this technique would result in a sufficient number of data points for a preliminary study.

If there were no bias in the human visual system we would anticipate that if we plotted the lengths of the generated lines at their respective angles, the ends of these lines should fall on a 6 inch semicircle, whose center is the middle of the horizontal standard (Fig. 3). However, this was not the case and a definite bias was observed (Fig. 4). The generated arc, depicted by points representing the average lengths of the lines at each orientation, is not semicircular but semi-elliptical. This result does support the work of Künnapas and the theory of the compressed celestial dome which naturally arises from a biased human visual field.

[7] Timothy J. Wrighton and Alexander M. Sadowski, "Retinal Processing of Geometrical Images", The Journal of the Colorado-Wyoming Academy of Science, Vol. VII, No. 6, (May 1975), p. 26.

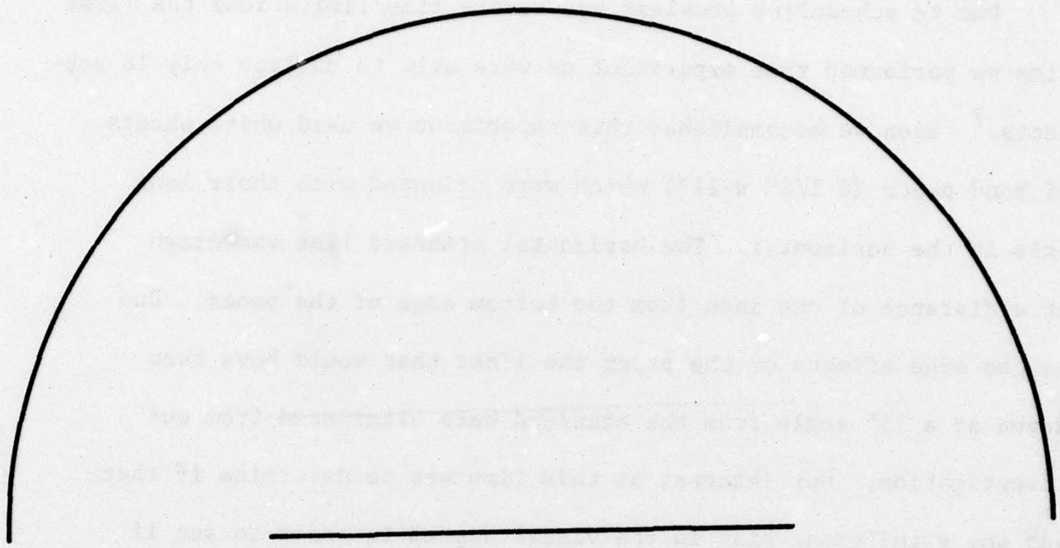

FIGURE 3. SHAPE OF THE TOP HALF OF THE UNBIASED HUMAN VISUAL FIELD.

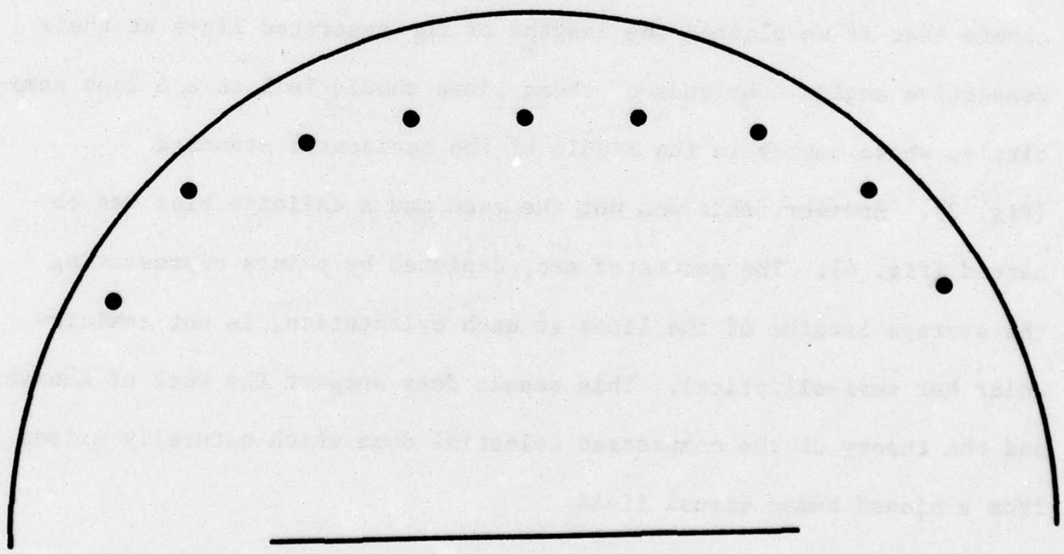

FIGURE 4. SHAPE OF THE BIASED VISUAL FIELD AS COMPARED TO THE TOP HALF OF THE UNBIASED VISUAL FIELD

(● – EMPIRICAL DATA)

THE UPRIGHT "T" EXPERIMENT[8]

At this Point we had sampled only the top half of the human visual field and for the sake of completeness it was necessary to do the same for the bottom half. During the 1976 spring semester we were fortunate to test 39 subjects. The same procedure was employed as before except all lines were drawn below the horizontal. Fortunately, at this time we were able to obtain a large quantity of oversize sheets of white paper (16" x 22"). Of course, the use of this larger paper eliminated any edge effects and allowed us to also obtain data at positions that were 15 degrees from the horizontal.

It should be noted that at this time we had hoped to test subjects in both the inverted "T" and the upright "T" orientations. However, scheduling the subjects became a definite problem. The total time that each subject had to do this experiment allowed only one oreintation. Consequently, we decided on obtaining a larger data base on only one orientation instead of splitting up our group; since we had not done the upright "T", or bottom oriented illusion, we elected to concentrate on that one. The empirical data obtained (Fig. 5) does confirm vertical compression of the visual field in this orientation also. In combining both sets of data (Fig. 6) we do notice that we have some strong evidence for Künnapas' theory of the oval shape of the human visual field. The question still arises as to why this bias exists.

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[8] The data and results from this second experiment were presented at the 47th Annual Meeting of the Colorado-Wyoming Academy of Science at the University of Colorado in Boulder on 23 April 1976: A.M. Sadowski, D.D. Dyche, and J.M. Reames, "The Fovea Centralis, the Key to the Retinal Processing of Geometrical Images."

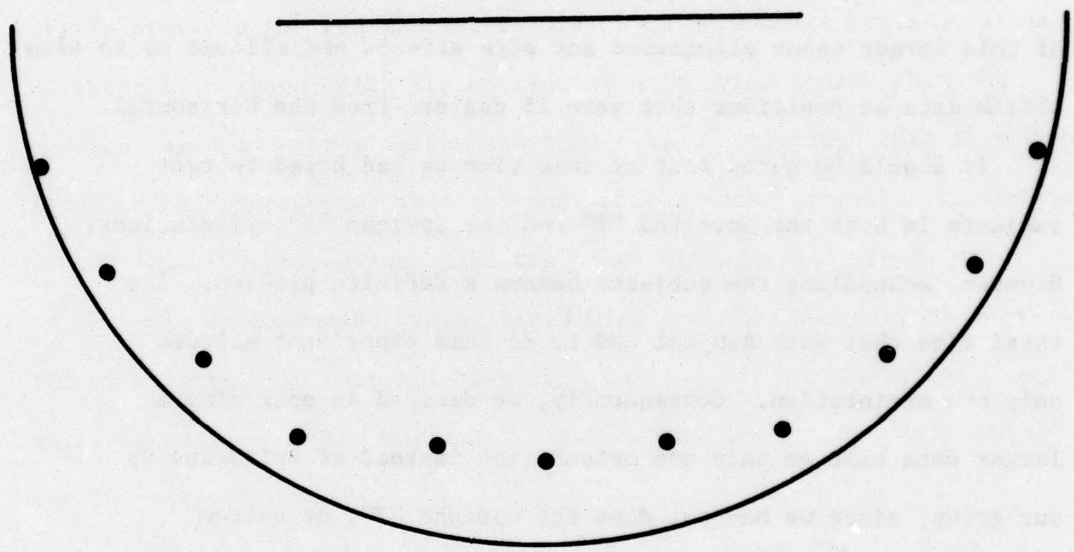

FIGURE 5. SHAPE OF THE BIASED VISUAL FIELD AS COMPARED TO THE BOTTOM HALF OF THE UNBIASED VISUAL FIELD.

(● – EMPIRICAL DATA)

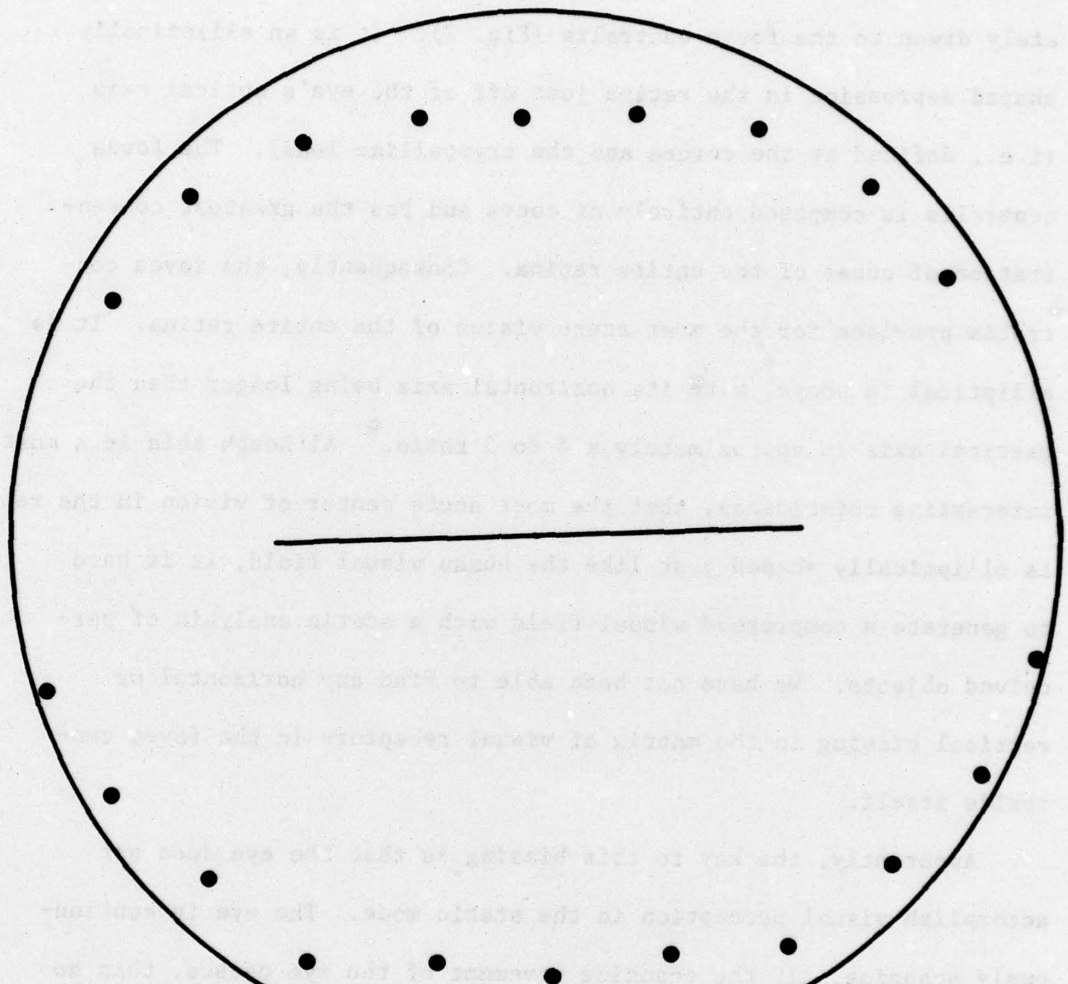

FIGURE 6. COMBINED VISUAL FIELD

(● – EMPIRICAL DATA)

THEORY

If we look to the retina to see if there is any significant structure that exhibits a horizontal-vertical bias we are immediately drwan to the fovea centralis (Fig. 7). It is an elliptically shaped depression in the retina just off of the eye's optical axis (i.e., defined by the cornea and the crystalline lens). The fovea centralis is composed entirely of cones and has the greatest concentration of cones of the entire retina. Consequently, the fovea centralis provides for the most acute vision of the entire retina. It is elliptical in shape, with its horizontal axis being longer than the vertical axis in approximately a 4 to 3 ratio.[9] Although this is a most interesting coincidence, that the most acute center of vision in the retina is elliptically shaped just like the human visual field, it is hard to generate a compressed visual field with a static analysis of perceived objects. We have not been able to find any horizontal or vertical biasing in the matrix of visual receptors in the fovea centralis itself.

Apparently, the key to this biasing is that the eye does not accomplish visual perception in the static mode. The eye is continuously scanning. If the scanning movement of the eye ceases, then so does the phenomenon of vision. Research has shown that whenever an image becomes stabilized on the retina either by immobilizing the eye or by optically compensating for the movements of the eye, the eye no

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[9] A.F. Deutman, The Hereditary Dystrophies of the Posterior Pole of the Eye (Assen, The Netherlands: Charles C. Thomas, Publisher, Van Goecum Co. N.V., 1971) p. 13.

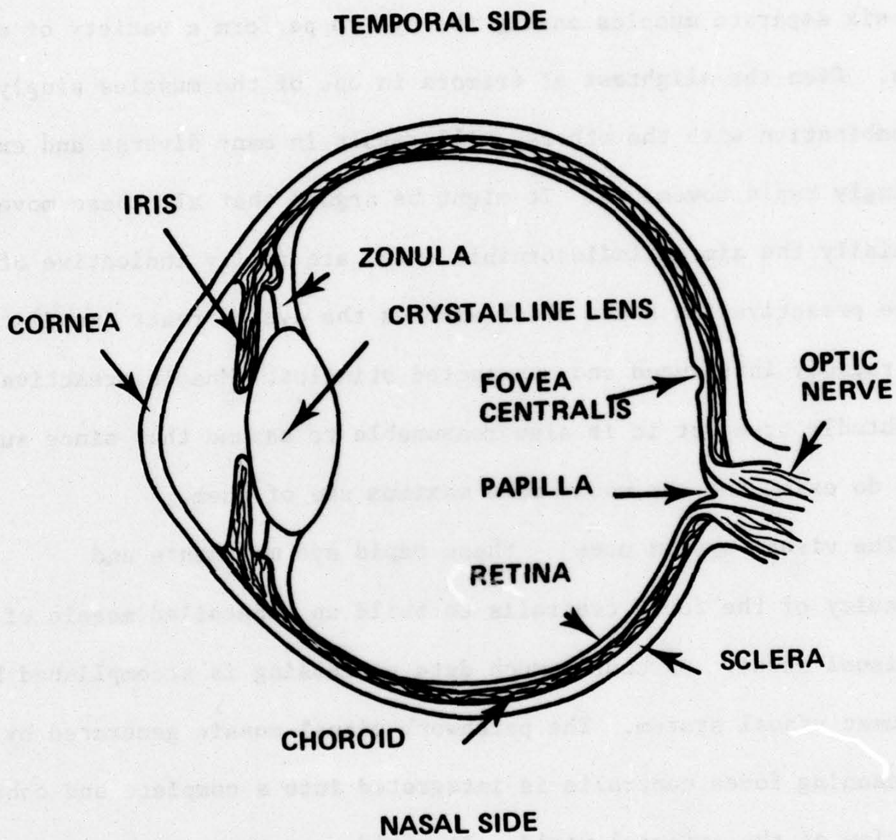

FIGURE 7. HORIZONTAL CROSS-SECTIONAL STRUCTURE OF THE HUMAN EYE

longer perceives the stabilized image.[10] Even when we think we are concentrating on a given object (i.e., fixating) and we cannot imagine that there is any eye movement, there are many varied and discrete eye movements employed by the human visual system, (See Table 1). If we were to look at the muscle structure of the eye (Fig. 8) we would see that six separate muscles enable the eye to perform a variety of movements. Even the slightest of tremors in one of the muscles singly, or in combination with the others, will result in many diverse and exceedingly rapid movements. It might be argued that all these movements, especially the almost indiscernible ones, are really indicative of a muscle preactivation state which enables the eye to react immediately to a rapidly introduced and unexpected stimulus. Muscle preactivation is undoubtedly true but it is also reasonable to assume that since such movements do exist the eye would make maximum use of them.

The visual system uses these rapid eye movements and the acuity of the fovea centralis to build up a detailed mosaic of the visual scene. Of course much data processing is accomplished by the human visual system. The patchwork visual mosaic generated by the scanning fovea centralis is integrated into a complete and cohesive view of the external world. It would seem that at the same time the fovea centralis is functioning as a scanning element it could very easily function as a size discriminator.

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[10] Hugh Davson, The Physiology of the Eye, 3rd ed (New York: Academic Press, 1972), pp. 251-252.

TABLE 1

INVOLUNTARY MOVEMENTS OF THE EYE DURING FIXATION*

Horizontal and Vertical

Tremor: Irregular oscillations of mean amplitude of 10-15 sec of arc
Frequency: 20 to 100 Hz
Maximum Angular Velocity: 20 min of arc per sec.

Flicks: (Saccades); Irregular, very rapid rotations.
Amplitude ranges from 1 to 25 min of arc.
Angular velocity: approximately 600 min of arc per sec
The intervals between two flicks vary from 0.03 to 5 sec.

Drifts: Slow oscillations and slow unidirectional movements whose amplitude does not exceed 5 min of arc.
Angular Velocity: on the order of 1 min of arc per sec.

Torsional Movements (Rotations about the visual axis)

Torsional Tremor - Amplitude of approximately 45 min of arc

Torsional Flicks - Amplitude of approximately 2 min of arc

*Adapted from the general discussion on p. 260, Adriana Florentini, "Dynamic Characteristics of Visual Processes", Progress in Optics E. Wolf, ed., North-Holland Publishing Company, Amsterdam, 1961.

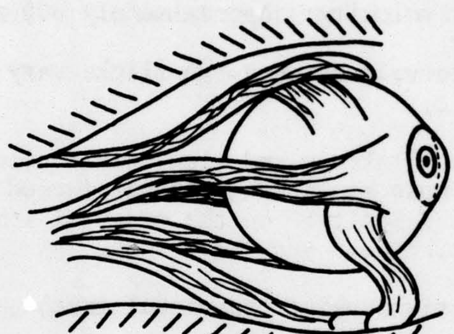

FIGURE 8. MUSCLE STRUCTURE WHICH ALLOWS FOR RAPID AND DIVERSE EYE MOVEMENTS

Because of its inherent high acuity the fovea centralis presents a much clearer and much more detailed view of the environment than any other part of the retina. The foveal region represents a discrete and highly focused part of the visual field whereas the rest of the retina represents a weakly defined or fuzzy region. This inhomogeniety allows the fovea centralis to function as a measuring stick.

Let us consider the task of determining visual equality in the case of two straight lines. First, the eye would scan one of the lines to determine how many foveal positions, placed end-to-end, would be required to cover the length of the line. Then it would scan the other line to see if an equal number of foveal positions would cover it. If the number of positions were the same then equality would be assumed. If the number were different then a relative size judgment would be made. For parallel lines, at any orientation, this sort of technique would be quite accurate. However, if the lines undergoing comparison were at some angle with respect to each other, an error would result. This error results from the elliptical nature of the fovea centralis and will be greatest in the comparison of horizontal with vertical lines. In fact, if a line is viewed in the horizontal and then is rotated to the vertical it will appear to grow in size. This apparent growth results because in the vertical the minor axis of the foveal ellipse is used as the measuring stick instead of its major axis. However, the eye cannot look in on itself and is not aware of the elliptical nature of its scanning

element. The eye assumes that the fovea centralis is circular and does not realize that the vertical axis is less than the horizontal axis of the foveal region. Herein lies the basis of the Horizontal-Vertical illusion. Due to the elliptical shape of the dominant optical scanning element in the human visual system a definite horizontal-vertical bias is applied to all visual scenes.

In order to verify this theory, a computer simulation was developed to mimic such a process. We used an ellipse, in which the ratio of its vertical axis to its horizontal axis was 3 to 4. As our standard we used a horizontal line equal in length to exactly 12 times the horizontal axis of the scanning ellipse. The computer was charged with the task of generating lines at every 5 degrees from the horizontal that would result from using 12 scanning ellipses as the only measuring device. We assumed that the eye would not make a perfect alignment with the generated straight line. We did not feel that the generated line would always be at the center of the ellipse. We did however make the constraint that the ellipse, in each of its scanning positions, must intersect the generated line and that it must make contact with the edge of the previous ellipse (Fig. 9). The generated visual field (Fig. 10) is indeed ellipsoidal but is somewhat smaller than our empirically generated one. Each line position is the mean of a hundred attempts by the computer to draw the given line. A random number generator was used to determine the exact position of the elliptical scanner with respect to the generated line. Our first thought was that we underestimated the ability of the eye to accurately track a straight line regardless of the line's orientation.

Our next attempt at generating the structure of the visual field was to assume that the eye could easily track straight lines and that the elliptical scanner would always be centered on the line. The result is still elliptical but is a better match to the empirical data (Fig. 11). The result is encouraging. We have generated an elliptical field, however, it is not a perfect match for our data. There is still something else to consider in this phenomenon.

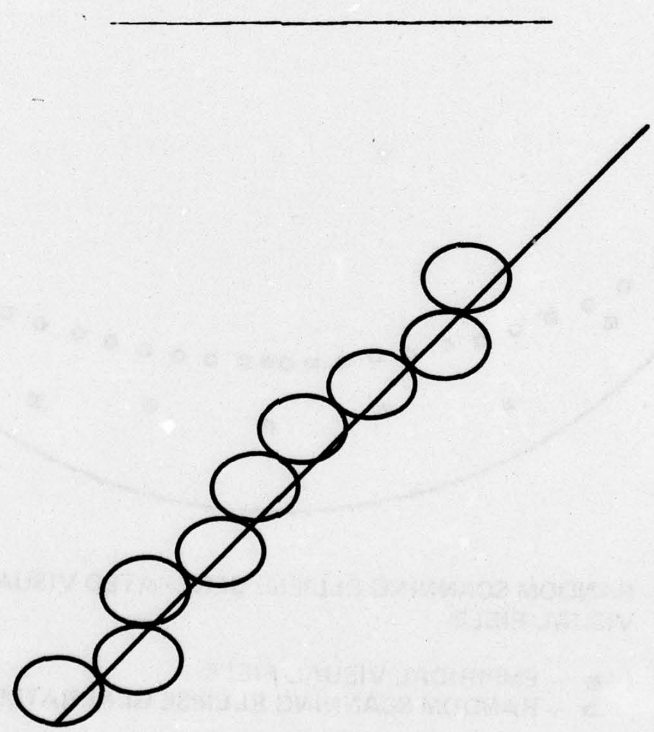

FIGURE 9. SIZE ESTIMATION BY THE FOVEA CENTRALIS IN A RANDOM SCANNING MODE

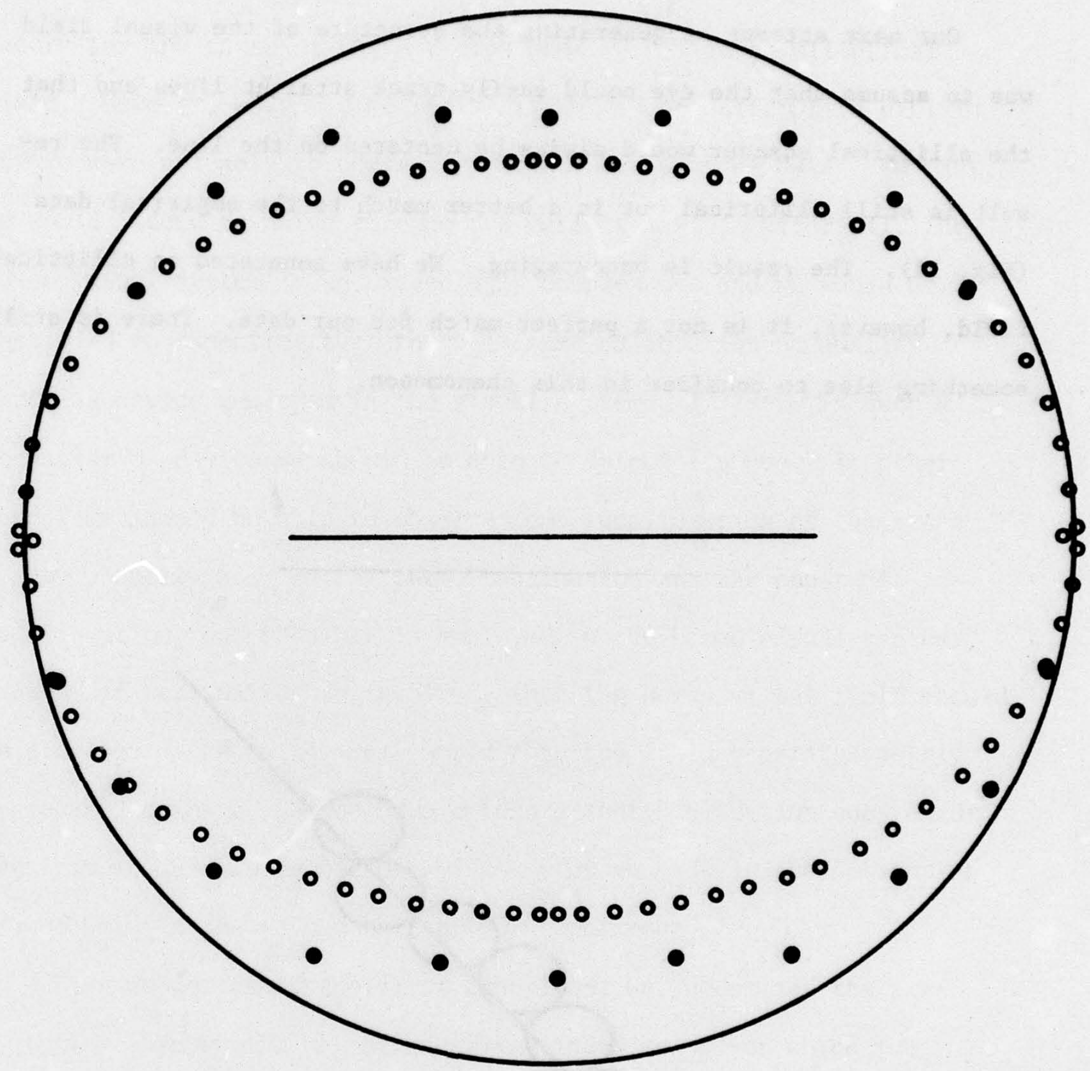

FIGURE 10. RANDOM SCANNING ELLIPSE GENERATED VISUAL FIELD VS. EMPIRICAL VISUAL FIELD

(● – EMPIRICAL VISUAL FIELD
o – RANDOM SCANNING ELLIPSE GENERATED VISUAL FIELD)

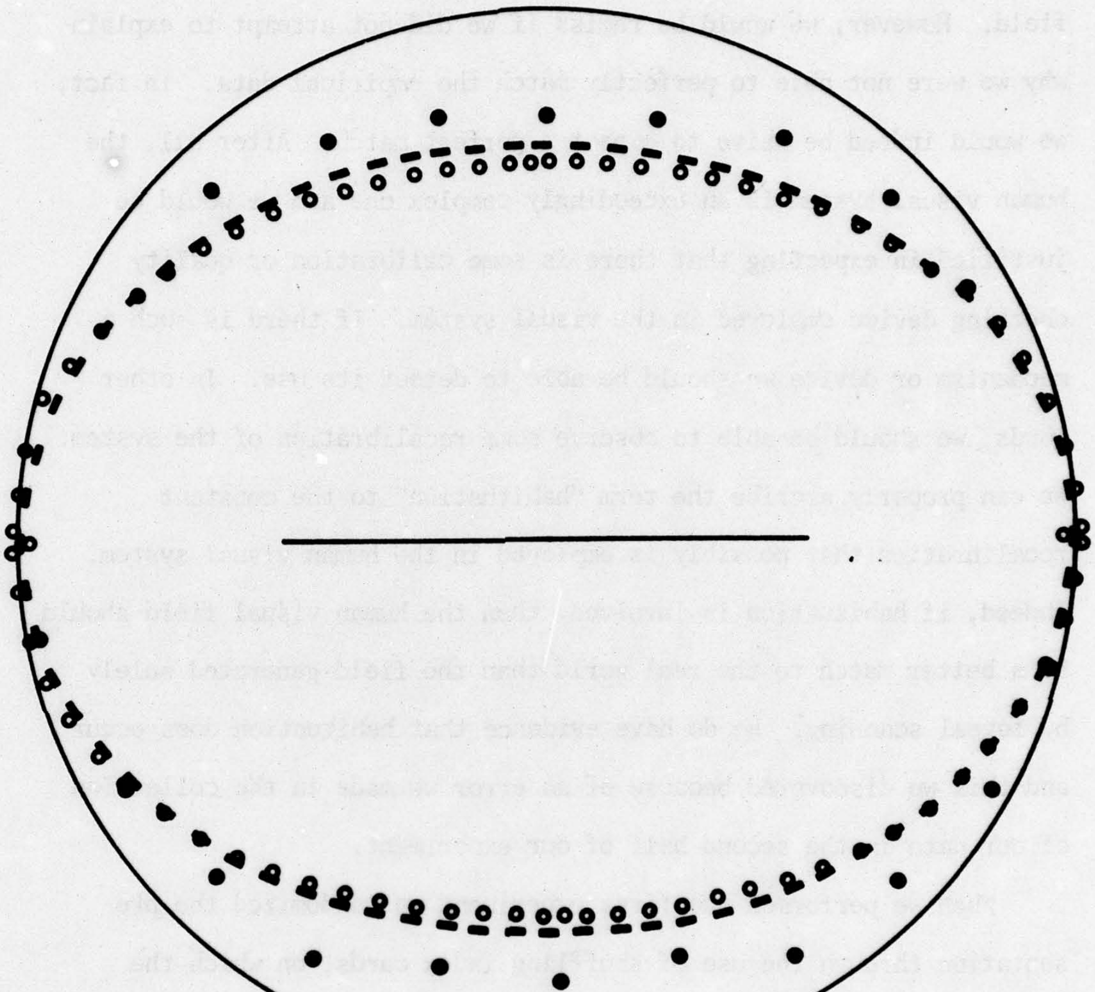

FIGURE 11. ORDERED SCANNING ELLIPSE GENERATED VISUAL FIELD VS. PREVIOUSLY GENERATED FIELDS

(▬ – ORDERED SCANNING ELLIPSE DATA)

THE ROLE OF HABITUATION

At this time we should derive some satisfaction since our theory for the cause of the H-V bias does result in an elliptical field. However, we would be remiss if we did not attempt to explain why we were not able to perfectly match the empirical data. In fact, we would indeed be naive to expect a perfect match. After all, the human visual system is an exceedingly complex one and we would be justified in expecting that there is some calibration or quality checking device employed in the visual system. If there is such a mechanism or device we should be able to detect its use. In other words, we should be able to observe some recalibration of the system. We can properly ascribe the term "habituation" to the constant recalibration that possibly is employed in the human visual system. Indeed, if habituation is involved, then the human visual field should be a better match to the real world than the field generated solely by foveal scanning. We do have evidence that habituation does occur and this we discovered because of an error we made in the collection of our data in the second half of our experiment.

When we performed the first experiment we randomized the presentation through the use of shuffling index cards, on which the angular orientations were indicated. One of our colleagues suggested that such a technique might be construed as being unsophisticated and suggested that we should avail ourselves of the computer random number generator. Falling prey to a greater degree of sophistication we decided to do so in the second set of our experiments. Consequently,

we used the random number generator to order our angular presentations. Since we were pressed by time we applied the same random ordering to each of our subjects. It was not until we were halfway through our subjects that we realized that our angular presentations were random for each subject but were ordered for the set of subjects, because each had received the same random sequence. Our first thought was to throw out the data, but on second thought we felt that additional information might be gained by reversing the random order for the second half of our subjects.

The results of the comparison of both sets of pseudo-randomized data are quite interesting and support our belief that the human visual system does continually recalibrate itself. Consider Figure 12; this is a plot of the first set of generated lines. Note that there is a point in the bottom left of the graph that represents an error greater than that exhibited by all the other points. This point corresponds to the mean length of the first line generated by the different subjects. All other attempts seem to give significantly more accurate estimates of the lengths of the required lines.

Figure 13 shows the data obtained from the second set of subjects. Note that here again there is a point that does not fit in smoothly with the rest of the data. It too was the first line estimated by all the subjects in the second half of the group accomplishing this experiment. Figure 14 shows both sets plotted together. The manner in which the points seem to complement each other in their positions suggests strongly that we have observed

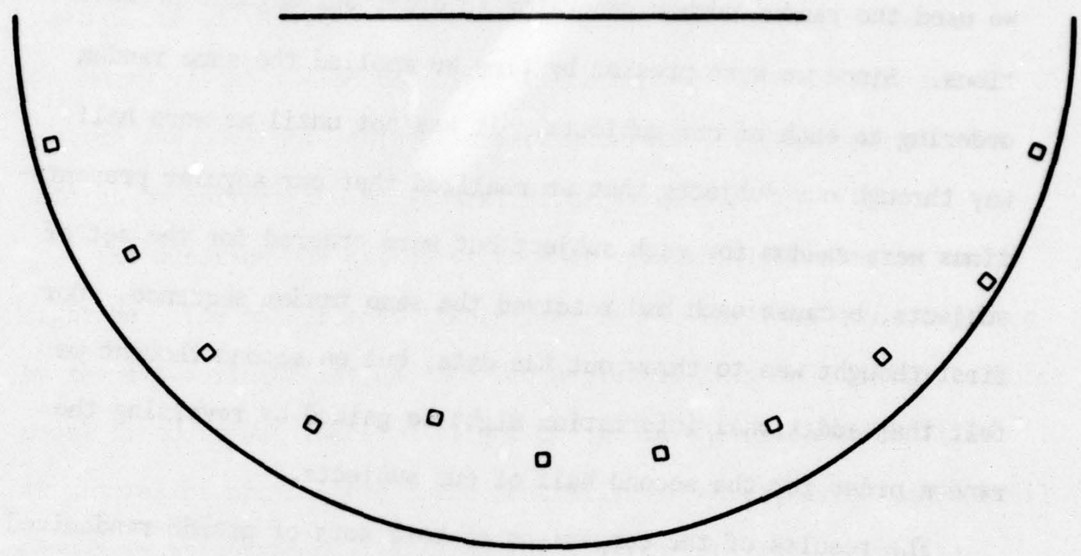

FIGURE 12. THE SHAPE OF THE BOTTOM VISUAL FIELD AS EMPIRICALLY DETERMINED BY THE FIRST SET OF SUBJECTS

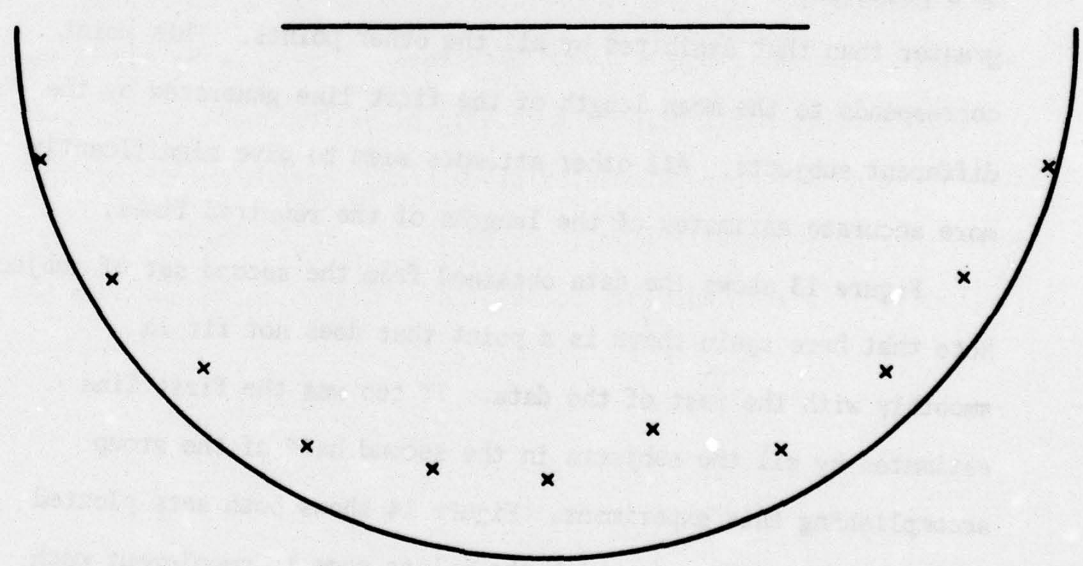

FIGURE 13. THE SHAPE OF THE BOTTOM VISUAL FIELD AS EMPIRICALLY DETERMINED BY THE SECOND SET OF SUBJECTS

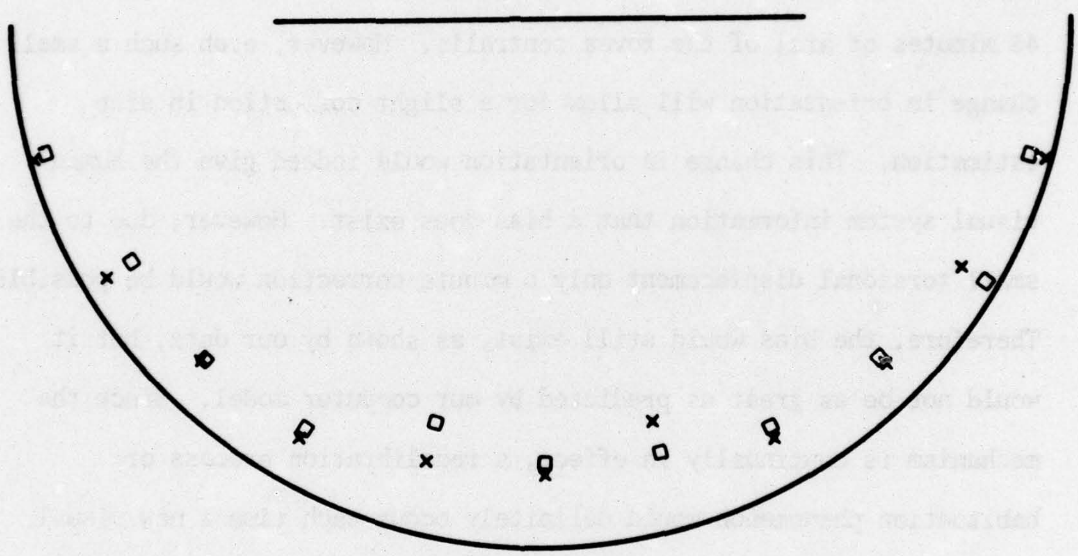

FIGURE 14. COMPARISON OF BOTH SETS OF DATA FOR THE BOTTOM HALF OF THE VISUAL FIELD

the effects of recalibration by the human visual system. However, the human visual system does seem to be conservative in this recalibration and does not achieve perfect accuracy but does nevertheless attempt to correct the horizontal vertical bias.

The question now arises as to what this recalibration mechanism might be. The answer most likely lies in the torsional mode employed by the eye during fixation. We had neglected this mode in our computer model since it was indeed a slight change in the orientation (i.e., 45 minutes of arc) of the fovea centralis. However, even such a small change in orientation will allow for a slight correction in size estimation. This change in orientation would indeed give the human visual system information that a bias does exist. However, due to the small torsional displacement only a minute correction would be possible. Therefore, the bias would still exist, as shown by our data, but it would not be as great as predicted by our computer model. Since the mechanism is continually in effect, a recalibration process or habituation phenomenon would definitely occur each time a new visual field is presented. Due to inherent time limitations and the nature of this mechanism, perfect calibration would never really result.

GENERAL DISCUSSION

In considering our endeavor, we are made to realize that we have only scratched the surface as far as the phenomenon of retinal image analysis is concerned. Even in the area of the H-V bias more work needs to be done. From our experience we feel justified in suggesting ideas for further research.

Our first suggestion would be to duplicate the experiment, but with a much larger sampling of individuals. One thousand subjects would be an ideal size. Of course sufficient time should be allowed to test each subject in both the upright "T" and the inverted "T" orientations. Also, the subjects should be exposed to the same experiment a number of times so as to determine if an upper limit does exist on the habituation phenomenon. It might appear to the reader that a thousand subjects would be an unnecessarily large sample. However, we could easily argue that statistically such a sample size may not be large enough. We need to document this illusion regarding possible differences according to:

Sex
Right Handedness vs Left Handedness
Age
Background
Profession
Corrected Vision vs Normal Vision
Indoor vs Outdoor Oriented Individuals
Binocular vs Monocular Insertion
etc.

This documentation would then give us a greater indication of how much of this phenomenon is physical and how much of it could be construed to be psychological.

Appendix F is a sample of the type of instructions that should be given to an individual who is about to be involved as a subject in such a study as ours. It should be noted that any instructions given to a prospective subject should be so worded as to impress the individual with the importance of such a study. We definitely want the individual's best effort. *However, the individual should under no circumstances be told the exact nature of the experiment.* By informing him of the specific phenomenon that we are testing for we could unduly prejudice even subconsciously his performance, thereby compromising the data. Consequently, much tact and ingenuity must be used in the exact wording of any instructions. In addition, all instructions and questions should be tested for ambiguity and clarity before any large scale formal testing is undertaken.

As an example of the problem of finding the right question to ask an individual to test a desired parameter, consider the question of whether or not an individual is more outdoor or indoor oriented. It would seem that all that would be required would be to ask him if he considered himself to be an outdoor or indoor type of individual. We asked this sort of question of our subjects in the inverted "T" experiment. We were interested in seeing if any significant difference in the H-V bias existed between those two types of individuals. Our interest in asking such a question centered on the fact that the outdoor individual would generally be subjected to a different type of visual field than an individual who tended to be more indoor oriented. In the case of the outdoor individual, the visual field would be of a

greater horizontal expanse than that typically experienced by the indoor individual. Also, the indoor environment would be more structured with the horizontal and vertical elements of this indoor structure being generally the same order of magnitude. Consequently, it would be reasonable to assume that a difference in the H-V bias between these two classes of individuals would be observed.

In theory, the indoor individual would have greater opportunity to utilize the habituation mechanism and should therefore be less subject to the H-V bias than the outdoor individual. An analysis of the data in our first experiment showed that no significant difference in these individuals did exist. It might be argued that we were rash in trying to isolate the influence of this parameter, since all our subjects were cadets and were all subject to the same environment and rigid life style. However, we believed that their backgrounds were sufficiently diverse before their arrival at the Academy so that their previous inclinations should have had some influence on their general perceptual abilities. In view of our results we appeared to be in error.

In the next set of experiments, when we utilized the upright 'T" orientation, we did not ask the indoor vs outdoor question bluntly. Instead, we asked the individuals what their favorite hobbies were. In analyzing our data we concentrated on the first hobby that they listed and used that to decide whether or not they were really what we considered to be indoor or outdoor oriented. The plotted data (i.e., Fig 15) show a remarkable difference between the two classes of individuals. It is indeed remarkable since all the subjects are cadets

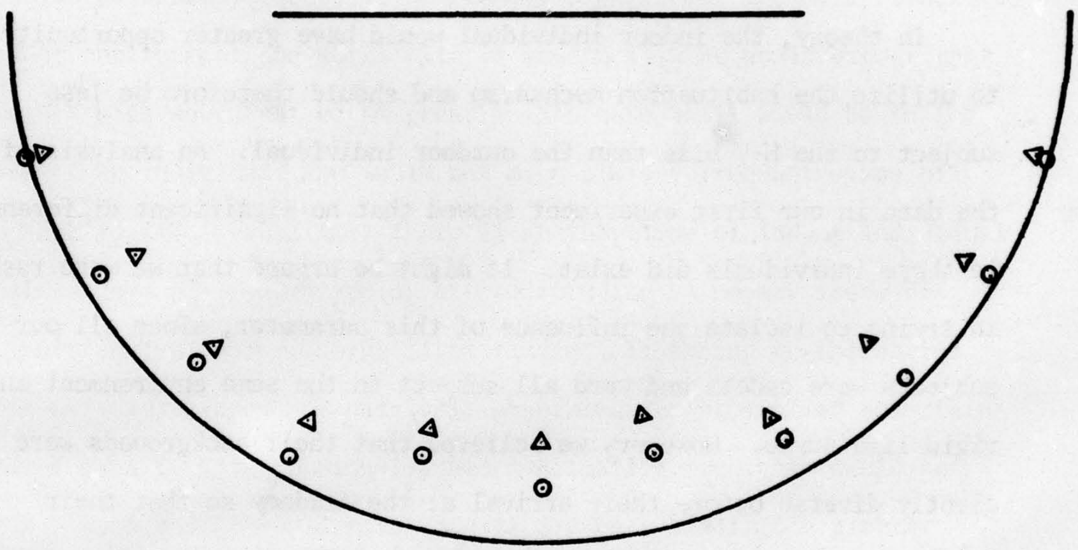

FIGURE 15. INDOOR-ORIENTED VS. OUTDOOR-ORIENTED DATA FROM THE UPRIGHT "T" EXPERIMENT
(o -INDOOR-ORIENTED, Δ - OUTDOOR-ORIENTED)

subjected to the same environment with very little spare time available to devote to their favorite pastimes.

The important parameter is not whether an individual considers himself to be an indoor or outdoor individual but exactly how he interacts with his environment. By bluntly asking an individual whether he is an indoor or outdoor type we, in all likelihood, have psychologically prejudiced him. Even the individual who has as his hobbies indoor activities may feel constrained to say that he is an outdoor type of individual. This response could result from the fact that as a cadet he is required to participate in frequent outdoor sports, outdoor military activities, etc. and thereby feels that by virtue of these frequent required activities he is an outdoor type of individual. On the other hand, an individual who might properly be called an outdoor type might feel constrained to call himself an indoor type since he is required to spend more time indoors than he would like. His studies, scheduled academic activities, cadet administrative duties, squadron meetings, etc., confine him to the indoors for a significant amount of time each day and consequently he may feel that he has been forced into being an indoor type of individual. This situation can be further complicated by the individual's ego. The subject may think that it is sophisticated to be an indoor type or he may think it is more manly or military to be an outdoor type. Consequently, how an individual feels about himself may not accurately indicate how he actively interacts with his environment. The better indicator would then be the nature of his favorite hobbies and pastimes.

The exact nature of the hobby must be considered carefully to determine how it can affect the habituation mechanism. If an individual has as his favorite hobby model building, stamp collecting, or a similar activity, it can be assumed that he places great emphasis on fine detail and consequently would be making great use of the habituation phenomenon. This type of individual would properly be considered indoor oriented. He readily experiences the more structured indoor environment and works with it and in it. We would expect that the H-V bias would not be as great in his case as it would be in the case of an individual who would not make similar frequent usage of the habituation mechanism. There is another type of indoor individual that is more passive regarding his surroundings. He may spend his leisure just sleeping, doing light reading, listening to the stereo with his eyes closed, or passively absorbing the programmed entertainment from a TV set. Obviously, his habituation mechanism would be little used and he would more than likely be subject to a greater H-V bias than the active indoor type of individual.

Outdoor individuals, who have as their most favorite pastimes activities such as cross country skiing or back packing, would be more subject to large horizontal expanses than either of our indoor types. They would probably be better at estimating horizontal distances but would be more susceptible to the H-V bias than the active indoor individual would. There are obviously other types of outdoor individuals who are very passive with regard to the outdoor environment and would therefore experience the H-V bias to an even different degree.

What the preceeding discussion has sought to demonstrate is that this phenomenon of the H-V bias is more complicated than can be inferred at a cursory look. Although the basis for it is a simple physical mechanism, the final results are indeed modified significantly by what might be properly called psychological considerations.

Future investigations should not be confined solely to the exact test that we employed. Different sizes and different figures should be utilized. A case that needs investigation is one in which the vertical line is maintained as the standard and the horizontal line is the generated variable. This horizontal line should be then rotated at different angles with respect to the vertical standard. One would expect that if an "L" presentation is used instead of the "T" presentation, the H-V bias would be modified, because the center of visual interest would be changed. In the "T" presentation, the natural visual center of interest is at the intersection of the horizontal and vertical lines. However, in the case of the "L" presentation, the natural visual center of interest is not well defined but is positioned in the space defined by the shortest angle between the two lines. The exact starting position would undoubtedly vary from individual to individual and would most probably vary in the same individual as he accomplishes a series of these tests. Consequently, the starting point for the foveal scanning process is considerably different in both cases.

More detailed investigation, physiologically and opthamologically, is required to pin down the exact structure of the fovea centralis.

One of our great problems was finding data on the exact size of the foveal ellipse. We did try to obtain retinal photographs like those obtained in laser eye exams. However, these are not readily obtainable since they are properly part of medical records and are subject to the privacy act. We were fortunate enough to find an individual who managed to have a copy of his laser eye exam photograph but it was of rather poor quality and much detail was lacking. Only the general area of the macula lutea was discernible. Consequently, we were forced to rely on the sparse information available in the literature. From our preliminary study we would have to assume that some of the variations that resulted in the standard deviations presented in the appendices were due to differences in exact sizes and shapes of the foveal ellipses of the different subjects. Our data leads us to believe that the foveal ellipse is on the order of a 3 to 4 ellipse and probably not much more elliptical than that. In some cases it may be more circular but probably not exceeding a minor to major axis ratio of 0.85 to 1.00. This, of course, is a rough estimation on our part.

Obviously, there is no dearth of approaches that can be applied to the investigation of the H-V bias in the human visual system. We most heartily encourage other investigators to look into this area. The process of image analysis is indeed intricate and complex and much more work is definitely needed in this area.

CONCLUSION

We believe we have demonstrated that the human visual field is not circular but elliposoidal. We have obtained sufficient evidence to indicate that the fovea centralis, in a dynamic scanning process, is the most probable cause for the horizontal-vertical bias in the human visual field. Also, we feel confident that we have isolated the torsional scanning mode of the fovea centralis as being the most probable physical mechanism that allows for a continual recalibration of the human visual system. We have called this recalibration mechanism the habituation phenomenon, since it allows the human visual system to more accurately interpret the real object world. Our study indicates that more research should be accomplished in this area and that the role of the fovea centralis as a size discriminator needs to be investigated further. We are convinced that the fovea centralis is a dominant and necessary mechanism in the retinal processing of images in the human visual system.

ACKNOWLEDGEMENTS

The author would like to formally express his appreciation to the following individuals for their assistance in this endeavor:

Second Lieutenant Timothy J. Wrighton (USAFA class of 1975) who assisted in the collection and reduction of the data for the bottom orientation of the H-V illusion.

Second Lieutenant J. Michael Reames (USAFA class of 1976) who assisted in the collection and reduction of the date for the bottom orientation of the H-V illusion.

Second Lieutenant David D. Dyche (USAFA class of 1975) who assisted in the literature search for the physiological information on the fovea centralis and in the computer programming of the Academy's Burroughs computer in the simulation of the foveal random scanning technique.

APPENDIX A

EMPIRICAL DATA FOR THE INVERTED "T" EXPERIMENT

Angle (degrees)*	$\bar{s}$ (normalized)**	σ (normalized)**
30	0.93	0.04
45	0.92	0.07
60	0.87	0.07
75	0.82	0.06
90	0.80	0.08
105	0.82	0.08
120	0.87	0.08
135	0.92	0.07
150	0.92	0.06

(N.B. $\bar{s}$ is the mean value of the lines generated by the subjects at that orientation.)

*These are Cartesian degrees. In other words, zero degrees is in the positive 'x' direction and 90 degrees is in the positive 'y' direction.

**The mean and standard deviation are normalized with respect to the horizontal standard.

General Characteristics

(18 Subjects)

Right Handed	Left Handed	Wears Glasses	Normal Vision	Outdoor Oriented	Indoor Oriented
14	4	2	16	8	10

APPENDIX B

EMPIRICAL DATA FOR THE UPRIGHT "T" EXPERIMENT

Angle (degrees)	$\overline{x}$ (normalized)	σ (normalized)
195	1.00	0.08
210	0.95	0.07
225	0.91	0.07
240	0.92	0.09
255	0.84	0.11
270	0.84	0.09
285	0.82	0.10
300	0.91	0.09
315	0.92	0.11
330	0.95	0.09
345	0.98	0.07

General Characteristics

(39 Subjects)

Right Handed	Left Handed	Near Sighted	Normal Vision	Outdoor Oriented	Indoor Oriented	Average Age
39	--	6	33	25	14	18.8 yrs

APPENDIX C

SHAPE OF THE RANDOM SCANNING FOVEA GENERATED VISUAL FIELD

Angle* (degrees)	$\bar{s}$ (Normal-ized)	σ (Normal-ized)	Angle* (degrees)	$\bar{s}$ (Normal-ized)	σ (Normal-ized)
1	1.013	0.017	50	0.808	0.084
5	1.007	0.015	55	0.784	0.106
10	0.998	0.013	60	0.767	0.105
15	0.984	0.016	65	0.751	0.122
20	0.965	0.017	70	0.737	0.125
25	0.942	0.022	75	0.725	0.125
30	0.915	0.036	80	0.720	0.103
35	0.887	0.046	85	0.714	0.107
40	0.861	0.050	89	0.709	0.142
45	0.832	0.086			

*Since this field is symmetrical about the "x" axis and also about the "y" axis only one quarter of the field is given. Therefore 0 degrees corresponds to either the positive or negative "x" direction and 90 degrees corresponds to either the positive or negative y directions.

APPENDIX D

SHAPE OF THE ORDERED SCANNING FOVEA GENERATED VISUAL FIELD

Angle* (degrees)	s** (Normalized)	Angle* (degrees)	s** (Normalized)
0	1.000	50	0.829
5	0.997	55	0.811
10	0.988	60	0.794
15	0.975	65	0.781
20	0.957	70	0.768
25	0.937	75	0.761
30	0.915	80	0.755
35	0.893	85	0.751
40	0.866	90	0.750
45	0.848		

*Since this field is symmetrical about the "x" axis and also about the "y" axis only one quarter of the field is given. Therefore, 0 degrees corresponds to either the positive or negative "x" directions and 90 degrees corresponds to either the positive or negative "y" directions.

**This is not a mean value but an exact value (i.e., to 3 decimal places) since an exact alignment of the fovea with respect to the scanning orientation is postulated. Consequently, no standard deviation is indicated.

APPENDIX E

HABITUATION DATA FROM THE UPRIGHT "T" EXPERIMENT

First Nineteen Subjects (Figure 12)				Last Twenty Subjects (Figure 13)			
Angle (degrees)	Presentation Order	σ (normalized)	$\overline{s}$ (normalized)	$\overline{s}$ (normalized)	σ (normalized)	Presentation Order	Angle (degrees)
195	10	0.06	0.98	1.01	0.09	6	195
210	3	0.07	0.94	0.96	0.06	11	210
225	7	0.06	0.91	0.90	0.09	2	225
240	9	0.07	0.91	0.92	0.11	8	240
255	1	0.09	0.80	0.88	0.11	5	255
270	4	0.07	0.84	0.85	0.11	4	270
285	5	0.09	0.85	0.78	0.10	1	285
300	8	0.08	0.90	0.92	0.10	9	300
315	2	0.11	0.91	0.92	0.11	7	315
330	11	0.09	0.98	0.92	0.09	3	330
345	6	0.06	0.97	1.00	0.07	10	345

APPENDIX F

SAMPLE INSTRUCTIONS TO BE GIVEN TO SUBJECTS
(N.B. the example is for the upright "T" experiment.)

You are about to take part in a research project which is under the guidance of (insert appropriate agency). The data will be used to further research in the physics of human visual perception. This research will have applications in the development of "heads up display" systems for pilots of high speed aircraft, the design of visual systems for remotely piloted vehicles, and will assist in the development of artificial visual systems for the blind. Please answer the following questions:

1. Are you right-handed or left-handed?
2. a. Do you normally wear prescription eye glasses?
   b. If so what vision defect do they correct?
   c. If you do wear glasses please wear them throughout the entire experiment.
3. What are your main hobbies?
4. How old are you?
5. Please indicate your sex on this form.

PERFORMANCE OF THE EXPERIMENT

You will see in front of you a sheet of paper with a horizontal line and a point underneath the line. You will note that the line is bisected by a visible dot. Use the pencil and the straight edge provided to draw a line through the two points. Make the length of the new line match as nearly as possible the length of the horizontal line. Do not use the straight edge to measure lines. The entire line

should be drawn <u>below</u> the horizontal line. In other words, begin the line at the midpoint of the horizontal line and draw it down through the point. Erasure of a line which appears to be too long is permitted. Keep your head in an upright position as much as possible. You will accomplish a series of these exercises.

APPENDIX G

INDOOR-ORIENTED VS OUTDOOR-ORIENTED DATA FROM THE UPRIGHT "T" EXPERIMENT.

Indoor-Oriented (14 Subjects)			Outdoor-Oriented (25 Subjects)		
Angle (degrees)	σ (normal-ized)	$\overline{s}$ (normal-ized)	$\overline{s}$ (normal-ized)	σ (normal-ized)	Angle (degrees)
195	0.07	1.01	0.98	0.08	195
210	0.06	0.98	0.90	0.09	210
225	0.07	0.94	0.88	0.08	225
240	0.07	0.97	0.89	0.09	240
255	0.13	0.87	0.82	0.10	255
270	0.09	0.90	0.81	0.08	270
285	0.09	0.86	0.79	0.10	285
300	0.06	0.94	0.89	0.10	300
315	0.08	0.98	0.88	0.11	315
330	0.06	0.99	0.93	0.10	330
345	0.07	1.00	0.97	0.06	345

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